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LINOSA AND ITS ROCKS

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INTRODUCTION

In the present paper are described the geology and petrology of a small islet in the Mediterranean which, up to the present, has remained almost unknown to geologists. The observations and collections on which the paper is based were made in September, 1905, in the course of a trip to some of the less-known volcanoes of the western Mediterranean, undertaken for the Carnegie Institution of Washington, to the trustees of which I am indebted for permission to publish this paper here.

About half-way between Malta and the coast of Tunis three small islets—Linosa, Lampedusa, and Lampione—project above the sea, which are called collectively the Pelagic Islands (Isole Pelagie). While geographically grouped together, geologically they are very diverse, Linosa being entirely volcanic, while Lampedusa and Lampione are composed wholly of limestone.

Although this paper deals properly with Linosa alone, it may yet be of interest to record a few facts about Lampedusa.[1] This island, the largest of the group, is of narrow, oblong shape, the greatest length (east and west) being eleven kilometers, and the greatest breadth (north and south) about three kilometers, almost at the eastern end. It is essentially a tilted block of limestone, the highest point being at the west (133^m), and thence gradually sloping to the east end, where the general elevation above sea-level is but 20^m. The surface, which is in general fairly flat, is somewhat cut up by shallow erosion valleys, and there are no very prominent hills. The soil almost all over the island is stony and barren, a few gardens and vineyards being maintained with difficulty here and there, and the only trees are half a dozen date palms which are found in sheltered hollows. The rock composing Lampedusa is a white to creamy-yellow, soft limestone,[1] which is distinctly magnesian, as shown by the analysis of Speciale,[2] who has described the island briefly. According to him it is more recent than the Tertiary limestones of Malta, containing fossils of living mollusks. Lampedusa is of considerable commercial importance as the center of extensive sponge and sardine fisheries, and is the point of exchange for the sponge trade of the Mediterranean, the sponges from the Greek islands being largely brought here.[3]

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[1] Cf. W. Deecke, *Italien*, Berlin, 1899 (?), p. 479; and *Italy*, London and New York, 1904, p. 449.

Lampione, which lies about 8 nautical miles west of Lampedusa, is a mere rock, barely 400 meters across, 43 meters high at its western end, and sloping to sea-level at the east. It is said to be composed of limestone similar to that which forms Lampedusa.

GEOLOGY OF LINOSA

Bibliography.—The literature on the geology of Linosa is very scanty, commensurate with its small size and isolation, and its political and commercial insignificance. For the most part the papers which deal with it belong to the first half of the nineteenth century and are of little modern value. A list of them is given by Speciale. The standard general works on volcanoes either ignore or barely mention the island, Scrope,[4] for instance, giving it but three lines of description.

Mercalli,[5] who bases his account on the work of Calcara[6] (an author whom I have been unable to consult), gives a page of description, with considerable detail as to altitudes, etc. He makes mention of but four volcanoes, but it is interesting to note that Calcara recognized the two periods of vulcanicity to be described later, though his "trachytic" rocks are shown by my observations and analyses to be basaltic tuffs, and were evidently referred to the trachytes because of their light color.

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[1] Lampedusa and Lampione are incorrectly colored as volcanic on Sheet 45 of the Carte géologique internationale de l'Europe. I saw no igneous rock on the island.

[2] S. Speciale, *Boll. Com. Geol. Ital.*, Vol. XV, 1884, p. 263.

[3] My thanks are due Signor S. di Maggio for courtesies and assistance during my few hours on Lampedusa.

[4] G. P. Scrope, *Volcanöes*, London, 2d ed., 1862, p. 345.

[5] G. Mercalli, *Vulcani d'Italia*, Milano, 1883, p. 161.

[6] P. Calcara, *Descrizione dell' isola Linosa*, Palermo, 1851, pp. 30.

The most recent, and the only modern, paper dealing with the geology is that of Speciale,[1] which is but a preliminary one, the second part, which was to describe the petrography of the rocks, never having appeared. In this two-page paper Speciale briefly describes the general geology and several of the volcanoes, distinguishing between those of tuff and of lava, the limits of which are given on his map.

The last paper to be mentioned is that of D'Avezac,[2] who gives a general description, apparently based largely on the observations of Captain Smyth prior to 1823. The geology is summarily treated, but the history of the islet is discussed more fully, D'Avezac showing that Linosa is the *Ἀνεμοῦσα* of Ptolemy.

Three maps of Linosa are available. The most satisfactory is that found on Sheet 211 of the charts of the Italian Instituto Idrografico, on a scale of 1 : 25,000, and which has been used as the base of that which accompanies this paper. A second is found on the Linosa and Lampedusa sheet (No. 193) of the British Admiralty, on a scale of 1 : 25,100, and this sheet is of special interest because it shows a view of the island from the southwest. The third is on Foglio 265 of the topographic maps of the Instituto Geografico Militare, the scale being 1 : 50,000. In all three the various volcanoes are shown and many altitudes noted, though, between the various maps, there are discrepancies as regards these and the names.

General description.—The island of Linosa[3] lies 20 miles northeast of Lampedusa and about 59 southeast of Pantelleria. In form it is nearly a square, the sides facing the cardinal points, with a length east and west of about 3 kilometers and a breadth north and south of

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[1] *Op. cit.*, p. 165, with map.

[2] D'Avezac, *Iles de l'Afrique*, Paris, 1885, p. 119.

[3] According to the British chart the lighthouse is situated in Lat. 35° 52′ N. and Long. 12° 53′ E.

2.5 kilometers, the greatest length diagonally from northwest to southeast being 3.5 kilometers. Its total area is about 6.5 square kilometers. On the map of the island as given in Fig. 1, the contour lines are only approximate and give merely a rough idea of the topography.

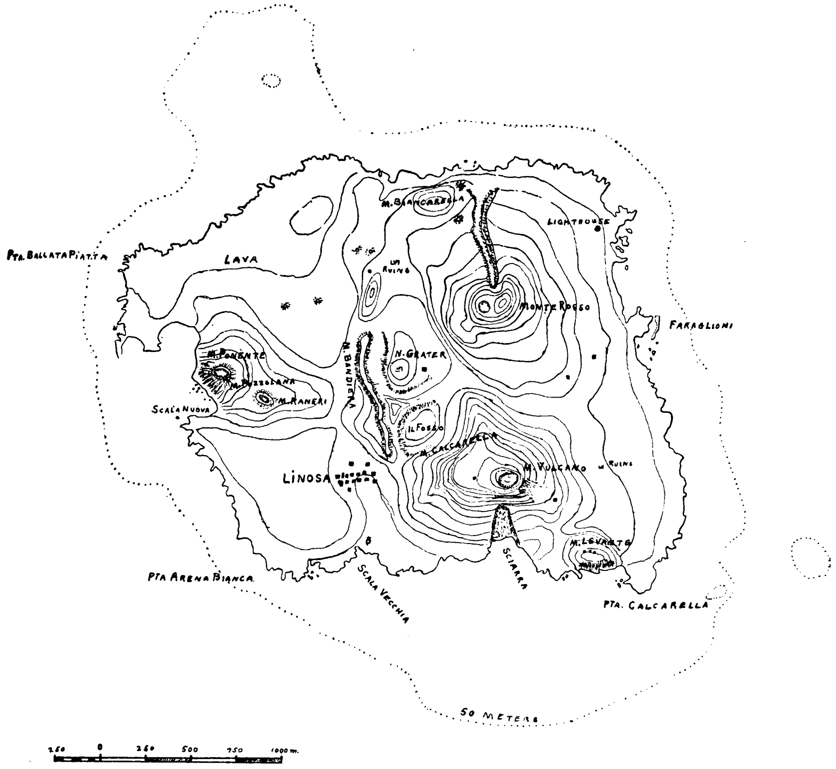

FIG. 1.—Island of Linosa.

Linosa is dry in the extreme, not a single spring being found on the island, and the water supply being dependent on the rains, which are collected from the flat roofs and preserved in cisterns. At the time of my visit the island was favored with the first rain in five months, and the inhabitants were reduced to a daily ration of two liters of water apiece, a supply having had to be brought by a government vessel from Sicily. The greater part of the surface, where it is not bare lava and tuff, is covered with sterile sand and ashes, and in the few cultivatable areas, which are fenced in with opuntia cactus (the fruit of which serves as food for man and the fleshy stems for beast), some sparse crops of grain are raised, or they are given over to straggling vineyards, from which a harsh, but not unpleasant, red wine is produced. Fishing is the only industry, and this barely suffices for local needs.

Communication with civilization is kept up by a small steamer, which touches at the island on its biweekly trip from Pantelleria to Girgenti, and again a day and a half later on the return voyage, touching at Lampedusa both ways. This interval was necessarily the limit of my visit, but the small size of the island enabled me to make a fairly complete study of its geology.

The earliest evidences of human occupation are seen in some ruins, which consist of long and narrow foundation walls, apparently of houses, built of blocks of tuff, and also several pot-shaped graves, lined with cement, which I saw near the summit of Monte Levante, and in which my guide said skeletons had been found. These, as well as vases and coins said to have been found on the island (none of which I saw), point to the habitation of the island in (probably) Roman times. But it was apparently abandoned during the Middle Ages and later, and remained uninhabited until 1845,[1] when some colonists were imported by the government. These earlier colonists inhabited several rude chambers hewn in the tuff on the west slope of Monte Bandiera, which are now unoccupied.[2] The modern village consists of a single street, with low, one-storied houses, and few houses are scattered about the island. At the time of my visit there were said to be about 240 persons residing on the island, including a customs officer, Signor N. Raneri, to whom I am deeply indebted for most courteous hospitality and assistance, a priest, and a government physician. A lighthouse occupies the northeast corner.

General geology.—The only rocks visible on the island are volcanic, and the whole mass has been built up out of the sea by a succession of eruptions which formed a number of cones. The only clue to what lies beneath these is given by a small fragment of a light-colored, medium-grained, olivine-bearing, hornblende-diorite, which I found imbedded in a piece of scoria at Monte Rosso, and which is evidently a fragment of a plutonic rock from the basement brought up by the lava stream. In this respect Linosa resembles Pantelleria, where Foerstner[1] reports fragments of hornblende-granite likewise imbedded in the lava and tuffs, and which he refers to the basement complex of the island.

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[1] Cf. Mercalli, *op. cit.*, p. 161, note. According to D'Avezac, Captain Smyth (before 1823) found no inhabitants nor, indeed, any animal life, except some falcons. He set free on the island some goats and rabbits, and planted peas, beans, wheat, barley, tobacco, and castor beans in various places, all traces of which benefactions having now disappeared.

[2] According to Deecke (*loc. cit.*) they were abandoned in 1878.

Small as is the island it yet shows nine distinct volcanic cones,[2] or centers of eruption, which may be referred to two distinct periods of activity, distinguished by the materials which compose them.

The first period is characterized by cones of basaltic tuff, lava being represented in these only as included blocks. Not only do these tuff cones show signs of greater age than the cinder cones in the greater extent to which they have suffered by erosion, but in many cases the tuffs are seen to be overlaid by the cinders and lavas of the cones of the second period.

In the center of the island is a rather prominent ridge of dark, greenish-gray tuff, running north and south, to which the name of Monte Bandiera is applied, and in the west slope of which the rude chambers mentioned above have been hewn. This ridge is the west wall of what is apparently the oldest cone of Linosa, to the east of it two distinct craters being visible. The most northerly of these, for which I could learn no name, but which may be called the North Bandiera Crater, is composed largely of yellow, with some dark-gray tuffs, which contain angular blocks of compact basalt. This crater, which measures some 300 meters across, is not very well preserved, but shows a well-defined rim on the west and south, the western rim being about 150 meters above the sandy and lava-covered plain to the west and about 20 meters above the crater floor. To the east its tuffs are lost beneath the lavas and cinders of Monte Rosso. This northerly crater is older than its companion, as the tuffs of the latter cover part of its southern side, and it may be considered the oldest on the island, in view of its poor preservation and central position.

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[1] H. Foerstner, *Boll. Com. Geol. Ital.*, 1881, p. 550.

[2] Speciale considers that there are but five eruptive centers, namely: Monte Ponente proper (with which he includes Monte Pozzolana), the cone which I have named Monte Raneri, Monte Vulcano, Monte Rosso (of which he mentions only the barranca on the north, not speaking of the summit crater), and Monte Bandiera (which includes the two large craters immediately to the east, as well as Monte Biancarella to the north). He considers Monte Calcarella as forming a part of Monte Vulcano and does not mention the well-defined cone of Monte Levante, nor does he consider that the tuff and lava cones belong to two distinct periods.

The southern crater, which is called Il Fosso, presents a flat, elliptical floor, of about the same size as that of the preceding, which is planted in vines and cactus. This crater is bounded on the north, west, and south by a well-defined rim of yellow and greenish-gray tuffs, which also contain blocks of compact basalt. This ridge reaches a height on the west, Monte Bandiera, of 102 meters, and on the south of 148 meters, this southern rim being known as Monte Calcarella. The south slopes of Calcarella are partly covered by the scoriae of Monte Vulcano, and to the east the low, ill-defined rim of Il Fosso is almost wholly buried beneath the lavas and ashes of this same volcano. A gap in the ridge on the southwest, between Monti Bandiera and Calcarella, gives access to the crater floor.

At the southeast corner of the island is a third tuff cone, that of Monte Levante.[1] Of this only the northern half remains, the southern portion having been washed away by the waves, forming a precipitous cliff and exposing a fine section, in an inaccessible outlying pinnacle of which was seen a dike of black basalt. What remains of the cone consists of thin-bedded yellow and dark, greenish-gray tuffs, which contain numerous, rather large, angular blocks of compact basalt. On the flat summit of the ridge, which is 92 meters above sea-level, weathering has developed in the tuff about these blocks a series of concentric thin shells, which resemble a nest of hemispherical basins in which the blocks lie. None of these shells were seen covering the blocks, that is, with the convexity uppermost. The origin of this peculiar structure is uncertain and, while it seems to be made evident by weathering, yet its cause must apparently be attributed to some other agency, possibly to the vibrations set up in the tuff by the impact of the falling block. The northern slopes of Monte Levante are covered by the scoriae of Monte Vulcano, which adjoins it on the northwest.

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[1] This is the name as given on the Italian military map, and the one by which it may best be called here, though my guide called it Monte Calcarella. But this last name is given on all the maps to the southern rim of the crater just described.

Monte Biancarella, which lies close to the north coast and immediately west of Monte Rosso, is a low, regular dome of yellow tuff, its summit about 50 meters above the base, and the whole about 150 meters across. There is no sign of a crater and the thin bedded tuffs dip quaquaversally on all sides, forming concentric, curving sheets, with step-like interruptions here and there due to erosion. The appearance is as if horizontal beds of tuff had been gently forced up by some invisible protrusion from below. Close to the south of this are some of the long foundation walls, constructed of blocks of tuff, which probably date from Roman times. They barely project above the surface. Excavation would be needed to expose them fully and would probably be repaid by some archaeological discoveries of interest, for which, unfortunately, time was lacking.

The last tuff cone to be described is marked Monte Ponente on all the maps, but seems to be called Monte Pozzolana by the inhabitants. As it is a composite cone, being composed both of tuff and lava, we may conveniently reserve the name Monte Pozzolana for the southern, tuffaceous portion, and let Monte Ponente denote specifically the northern, basaltic portion, though there is no orographic distinction between them. This cone is situated on the west coast of Linosa, the sea having cut away its west side and exposed a fine section. Immediately at its foot is the best landing-place of the island, a small cove, with rocky shores and a small artificial jetty, at which only small row boats can land, the steamer stopping about a mile from shore. If the wind is from the north or west, landing must be effected at the Scala Vecchia, a small bay on the south coast, likewise very rocky, and about one-third of a kilometer south of the village.

Monte Pozzolana consists of thin-bedded, very friable, yellow tuffs, which contain numerous very small fragments of somewhat scoriaceous basalt, but few large blocks, such as were noted at the other tuff cones. Toward the top the tuff mingles with, and is finally covered by, the scoriae of Monte Ponente. In the breach on the west side is a vertical dike about 70 centimeters wide, of finely vesicular black basalt, which cuts through the yellow tuff beds, but not through the black scoriae above. The sides of this dike show distinct marks of flow, and it has not altered appreciably the yellow tuffs.

Of the cinder and lava cones, which mark the second period of vulcanicity, the highest is Monte Vulcano, immediately southeast of Monte Calcarella, and on the south coast of the island. The summit of this I measured with an aneroid as 199 meters above sea-level, while the Italian military map gives it as 195 meters, and the Italian hydrographic map as 160.[1] About 14 meters below the summit of this volcano is a well-preserved, circular crater, about 100 meters in diameter and 30 meters deep, the steep walls composed of scoria and blocks of lava. On the south slope of the volcano, toward Monte Levante, are many vesicular lava flows, interbedded with tuffs, and lava flows and cinder slopes are also seen on the east side. On the west side, some 80 meters below the summit, is an almost horizontal plateau, the upper surface of a series of six or eight lava flows, each a meter or so thick, frequently with a rough columnar structure, and separated from each other by thin layers of scoriaceous material. On the upper edge of this plateau is a natural pit, with an orifice about two by three meters across, and about fifteen meters deep, so far as one can see, from which issues constantly a strong stream of cold air, resembling a somewhat similar orifice at the Kaimeni, on Methana, in Greece, and the *bufadores* of Catalonia. On the south slope, below this plateau, are some bedded tuffs and a steep *sciarra* of lapilli which extends down to the water's edge and which closely resembles that of Stromboli. Elsewhere the sides of the cone are covered with scoriae and blocks of lava, with small lava flows here and there. As was noted above, the products of this volcano cover the lower slopes of Monte Calcarella on the northwest and of Monte Levante on the southeast, thus showing its later date.

The next highest cone of Linosa is Monte Rosso, in the northeast corner of the island. According to my aneroid this is 196 meters high, while the Italian maps give it as 186 meters, and the English one as 610 feet (186^{m}), so that it is only a trifle lower than Monte

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[1] The British Admiralty chart gives the height as 525 feet (129^{m}), which is certainly much too low, and is possibly an error for 625 feet (191^{m}).

Vulcano. This is a typical, breached cinder cone, the outer slopes well preserved on the east, south, and west, but opened up on the north flank by a long, narrow, and deep *barranca*, which leads up nearly to the top, the upper part being edged by a narrow *arête* of rough lava on either side. Near the summit is a well-defined, almost circular crater, some 75 meters across, and whose floor is 20 meters below the highest point of the rim on the north, between it and the head of the barranca. Monte Rosso is composed almost wholly of rough scoriae and lapilli, to whose general red color the name of the cone is due, though some blocks of compact lava are seen here and there, and flows from near the base and from the mouth of the barranca have covered the island to the northeast, north, and northwest. Possibly some of the lavas to the south also belong to this cone, but the line of demarkation between these and the lavas of Monte Vulcano laid down on Speciale's map could not be made out by me, the surface being covered largely with sand and soil and partly given over to cultivation.

Immediately to the west of the mouth of the northerly barranca, and east of Monte Biancarella, is a small parasitic cone of reddish scoria, in which were found crystal fragments of feldspar and of a black hornblende, which is peculiar in containing 8.47 per cent. of TiO_2, and which will be described elsewhere. The occurrence of hornblende here is mentioned by Speciale. Similar crystals are said to be found at one other spot, on the east coast near I Faraglioni, south of the lighthouse, but I did not visit this locality.

The third cinder cone is that of Monte Ponente, on the west coast, which, as we have seen, is in close conjunction with the tuff cone of Monte Pozzolana, joining this on the north. At the summit, which my aneroid made out to be 98 meters above sea-level, (the Italian military map giving 107, and the Italian hydrographic map 92), is a small circular crater, with a diameter at the bottom of about 33 meters and a depth of 25 meters. The walls are precipitous and are composed of scoriae and lava blocks.

This volcano has poured out several large flows to the north and northeast, the place where the uppermost one of these has broken through the underlying yellow tuff of Monte Pozzolana being well seen in part of the section exposed by sea action on the northwest.

About half-way up a massive stream of black basalt, several meters thick, pierces the tuff, which it has reddened for some distance around. On the west coast, south of Ballata Piatta Point (the northwest corner of the island), six superposed flows are visible, which vary in thickness from one-half to one meter, and are separated from each other by scoriaceous bands. These flows of Monte Ponente, the surface of which is very rough and wholly devoid of cultivation, cover the surface to the northwest, north, and northeast of the cone, and extend into the sea, forming a very jagged shore line. On this lava surface, to the northeast of Monte Ponente and to the northwest of Monte Bandiera, are large knolls and hummocks of rough, large lava blocks, rudely piled on one another. These are apparently the remains of fallen-in lava caverns, or are possibly due to local explosions of steam.

From the relations of the two it is clear that the lavas and scoriae of Monte Ponente were ejected from the north flank of the already formed tuff cone of Monte Pozzolana, and that the two are geographically but a single mass, though petrographically quite distinct. So far as can be seen, however, there was only a little shifting of the vent northward when the second period was initiated.

To the east of Monte Ponente is an unnamed cone, for which I propose the name of Monte Raneri, after that of my host. This is 73 meters high, and shows a well-defined elliptical crater at the summit. The greater part of this cone is scoriaceous, but some lava flows are visible, and there are many blocks of a compact basalt, which differs from the others on the island in the greater abundance and size of the olivine phenocrysts. Monte Raneri is evidently older than Monte Ponente, as the scoriae of this latter cover the northwest flanks of the former.

From the characters and relations of the tuff and of the lava and cinder cones, it is quite clear that the former belong to an earlier and distinct period of activity. The tuff cones are all lower than those of the other kind, and their forms have suffered much more from erosion and their craters are not as well preserved, though this is probably due in part to the difference in the materials. Furthermore, as we have seen, when the two occur together the tuffs underlie the scoriae and lavas. Also, at Monte Pozzolana and Monte Levante

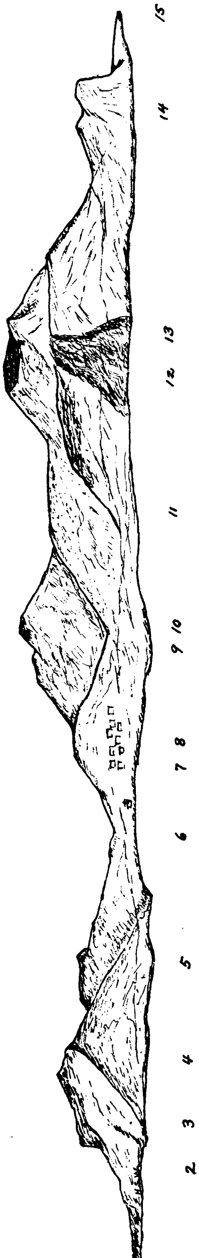

FIG. 2.—Linosa from the Southwest. 1, Ballata Piatta Point; 2, Scala Nuova; 3, Monte Ponente; 4, Monte Pozzolana; 5, Monte Raneri; 6, Scala Vecchia; 7, Linosa Village; 8, Monte Bandiera; 9, Il Fosso; 10, Monte Rosso; 11, Monte Calcarella; 12, La Sciarra; 13, Monte Vulcano; 14, Monte Levante; 15, Calcarella Point.

dikes and flows of basalt penetrate the tuffs. But it seems to be equally clear that, while the period of formation of the tuff cones antedated that of the lava ones, yet that in some cases, at least, the closing phases of the tuff cones coincided with the activity of the lava and cinder ones, as is shown by the intercalation of tuffs and lavas on the southeast slope of Monte Vulcano, and the intermingling of the tuffs of Monte Pozzolana and the scoriae of Monte Ponente in the upper portions of the mass. The usual presence of blocks of lava, scattered through the tuffs, points to the existence of lava flows beneath the surface at the time of the tuff eruptions, fragments of which were hurled up with the looser material. It might seem that the blocks in the tuff of Monte Levante have been ejected from the neighboring Monte Vulcano, as they are especially prominent in the upper beds. But this supposition is negatived by the fact that, while chemically similar to the later lavas of Vulcano, they belong to a different petrographic type, similar to that of the blocks in the other tuffs, and quite distinct from the usual types of the later lavas, as will be brought out later.

As to the geological age of these eruptions, the total absence of sedimentary and fossiliferous rocks precludes any definite evidence. But the well-preserved state of the cinder cones, the sharpness of outline of their craters and of the barranca at Monte Rosso, and the general freshness of their lavas and scoriae, point unmistakably to their eruption in recent times. The lack of almost any reference to the island by ancient writers leaves us without any documentary data, but the presence of the graves in the tuffs of Monte Levante and of ruins near Monte Biancarella and in the north crater of Monte Bandiera proves that the extinction of these tuff cones, at least, antedates human occupation. No hot springs nor other evidences of present vulcanicity are found on the island, and its volcanoes must be regarded as extinct.

To recapitulate the apparent facts as to the order of eruption of the several cones, my observations show that the tuff cones belong to an earlier period than those of lava, though it is probable that the two periods overlapped to a slight extent. Of the former the north crater of Monte Bandiera is almost certainly the oldest on the island, followed, probably soon after, by the south crater, the so-called Il Fosso. Monti Levante, Pozzolana, and Biancarella are, almost unquestionably, later than these, and it seems probable that the date of the two former is prior to that of the last named, though the exact order is impossible to ascertain. It is more difficult to determine the sequence of the lava and cinder cones, as the relations of their several flows when adjoining, are, except in one instance, obscured by superficial sands, ashes, and cultivated soil. From their size it would seem reasonable to ascribe the eruptions of Monti Rosso and Vulcano to a rather early period, while Monte Raneri is probably of a later date, and is certainly earlier than Monte Ponente, the eruption of which may be regarded as closing the era of volcanic activity.

From the submarine topography indicated on the map (Fig. 1), it is probable that submarine eruptions, similar to those of the islands of 1831 and 1891 near Pantelleria, have taken place to the north and to the southeast of Linosa. It may be noted that rock is indicated on the chart as forming the sea-bottom at both these points, surrounded by sands.

In Fig. 2 is shown a view of the island from the southwest, based on a sketch made by me when leaving the island, as, unfortunately I had no camera with me during my visit. While somewhat diagrammatic, it yet shows the relative positions, shapes, and sizes of the various cones, each of which may be easily identified, as well as the general appearance of the island.

PETROGRAPHY OF LINOSA

The lavas of Linosa are all feldspar-basalts according to the prevailing rock classifications, though a few contain very small amounts of nephelite, but scarcely sufficient to entitle them to the name of nephelite-basalt if account be taken of the quantitative relations. According to the quantitative system of classification recently proposed,[1] they are similarly monotonous, all of those analyzed and presumably all the others collected, so far as can be judged from the microscopic examination, falling in the subrangs camptonose (III. 5. 3. 4) and auvergnose (III. 5. 4. 4–5). Mineralogically they are very uniform and simple, the only constituent minerals being plagioclase, augite, olivine, and titaniferous magnetite, with occasionally some glass and traces of nephelite in a few instances. In the basalts themselves neither hornblende nor biotite could be detected, though crystals of hornblende occur loose in scoria at one or two points, as was noted above. The tuffs have apparently been derived from basaltic magmas, and will be briefly described after the basalts.

While the basalts vary from quite compact to highly vesicular and scoriaceous forms, such differences may be disregarded as being purely adventitious. They are all porphyritic, phenocrysts of olivine and of augite being present in every case, accompanied by abundant ones of feldspar in many of the flows, while in others feldspar phenocrysts are rare. But in the great majority of cases these megascopic differences largely disappear in the thin section, and even megascopically the extremes grade into one another to such an extent, and are connected by so many transition forms, that, as regards the majority of the rocks, a well-marked separation of the two is impossible, while the extremes may be referred to two distinct types, chiefly characterized by the abundant presence or almost complete absence of feldspar phenocrysts, as well as by certain slight chemical differences. A third type is more distinct, but even this would probably be found to intergrade with the others, were more specimens available.

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[1] Cross, Iddings, Pirsson, and Washington, *Quantitative Classification of Igneous Rocks*, Chicago, 1903.

As has been explained elsewhere,[1] in connection with the Catalan basalts, since the modes and textures of these basalts are usual ones, represented by much better- and longer-known rocks, the types will not be designated systematically and definitively by the use of typal adjectives, but will be distinguished provisionally by prefixing to the magmatic name the name of a representative locality on the island.

CAMPTONOSE-AUVERGNOSE (FELDSPAR-BASALT), MONTE PONENTE TYPE

Megascopic characters.—In the hand specimen these rocks vary in color from a rather dark gray to black, and are sometimes compact but more often decidedly vesicular, highly scoriaceous forms being abundant. They are decidedly porphyritic, thin, tabular phenocrysts of white feldspar, from 2 to 4^{mm} long, being abundant, with fewer of olivine, 1 to 3^{mm} in diameter, usually pale yellow, but occasionally golden or rarely greenish, and still fewer of dark, greenish-black augite.

Microscopic characters.—In thin section the feldspar phenocrysts are seen to be wholly of labradorite, almost invariably twinned both according to the Carlsbad and the albite laws, the extinctions indicating a composition of about $Ab_1 An_1$. A zonal structure is rarely seen, the core being then more calcic, but the interior is not infrequently occupied by a sponge-like mass of inclusions, either of brownish glass or of augite and magnetite grains. The augite phenocrysts are rarely visible and present no features of special note. They are usually fragmentary or stoutly prismoidal, quite colorless, or less often pale gray, quite free from any zonal structure, and containing generally some inclusions of magnetite. The olivine phenocrysts, which are more abundant than those of augite, are colorless, usually highly euhedral, showing the common lozenge-shaped outlines, but occasionally with the edges corroded, especially on the faces of the domes and prisms. In most of the specimens the olivine phenocrysts are perfectly fresh, borders of iddingsite being extremely rare.

The ground-mass in which these lie is usually a typically intersertal one, thin tables of plagioclase, which has the same composition as that of the phenocrysts ($Ab_1 An_1$), being quite abundant and usually divergently arranged. Between these feldspar laths is a granular aggregate of small, colorless augite anhedra, which are generally equant rather than prismoidal, and many opaque grains of magnetite, small grains of olivine and apatite prisms being rarely seen in the ground-mass. While some of the specimens seem to be holocrystalline, others are distinctly vitreous, and in these the femic constituents are not well crystallized, but are represented by dusty, dark specks, which render the ground-mass almost opaque. This is especially well seen in the rock which forms the dike at Monte Pozzolana. In this type nephelite seems to be rare or wholly wanting.

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[1] H. S. Washington, *American Journal of Science*, Vol. XXIV, 1907, p. 229.

Mode.—The small size of the ground-mass constituents, especially of the augite and magnetite anhedra, and the great extent of overlapping, do not permit a satisfactory estimate of the mode by Rosiwal's method. But by making certain readjustments of the norm as calculated from the chemical analysis, the mode of the upper north flow of Monte Ponente was estimated to be approximately as follows:

Labradorite (Ab_1An_1)	57
Augite	26
Olivine	6
Magnetite (titaniferous)	10
Apatite	1
	100

The abundance of labradorite, and the relatively much greater amount of augite than of olivine, are the distinguishing features of this mode.

Chemical composition.—Two analyses of this type were made by me, one being of the uppermost, and the other of the lowest accessible, north flow of Monte Ponente. Parts of this latter flow showed a white mineral (gypsum) in the vesicles, but a specimen free from this was chosen for analysis. The gypsum itself will be described later. In this, as well as in the other analyses made of the basalts, especial attention was paid to the determination of titanium and nickel, the presence of which is so often disregarded, as these constituents have been found to be of considerable importance in considering the correlations of the Linosa rocks. Analysis No. II has been previously published,[1] but in a less complete form.

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[1] H. S. Washington, *Quarterly Journal of the Geological Society*, Vol. LXIII, 1907, p. 75.

	I	II	I*a*	II*a*
SiO_2	48.06	48.84	0.801	0.814
Al_2O_3	15.90	14.62	0.156	0.143
Fe_2O_3	3.37	2.08	0.021	0.013
FeO	7.97	9.00	0.111	0.125
MgO	7.11	7.15	0.178	0.179
CaO	9.37	9.33	0.168	0.166
Na_2O	3.19	2.86	0.050	0.039
K_2O	0.85	0.89	0.009	0.010
H_2O+	0.40	0.49	.....	.....
H_2O-	0.06	0.07	.....	.....
CO_2	none	none	.....	....
TiO_2	3.31	3.57	0.041	0.045
ZrO_2	....	none	.....	.....
P_2O_5	0.36	0.36	0.003	0.003
SO_3	....	0.05	.....	.....
Cl	0.14	0.42	0.002	0.006
Cr_2O_3	none	none	.....	.....
MnO	0.06	0.04	0.001	0.001
NiO	0.09	0.08	0.001	0.001
CuO	none	none	.....	.....
BaO	....	none	.....	....
SrO	....	0.04	.....	....
	100.24	99.89		
$O=Cl$	.03	.09		
	100.21	99.80		

I. Auvergnose-camptonose (feldspar-basalt). Upper north flow of Monte Ponente, Linosa.

II. Auvergnose (feldspar-basalt). Lower north flow of Monte Ponente, Linosa.

I*a*. Molecular ratios of I.

II*a*. Molecular ratios of II.

The two analyses are very closely alike, there being no noteworthy difference between the uppermost and the lowermost flow. The small amounts of chlorine shown in these were extracted by water, and belong (with equivalent amounts of sodium) to salt derived from the sea-water, the waves of which break over the lavas. In the columns of molecular ratios these amounts of Na_2O (0.002 in I and 0.006 in II) have been deducted. The small amount of SO_3 in II indicates the practically complete absence of gypsum in the specimen analyzed. Among details to which attention may be called are the great preponderance of ferrous over ferric oxide, and the high figures for titanium dioxide and nickel oxide, features which will be discussed at length on a later page. The absence of copper, zirconium, chromium, and barium, and the presence of but traces of strontium, may also be noted.

Classification.—The norms of the preceding analyses, on which their classification according to the quantitative system depends, are shown in the adjoining table.

Norm of I	
Or	5.00
Ab	26.20
An	26.97
Di	13.63
Hy	10.30
Ol	5.31
Mt	4.87
Il	6.23
Ap	1.00
Rest	0.75
	100.26

Ratios of I

$\frac{\text{Sal}}{\text{Fem}}=\frac{58.17}{41.34}=1.41.$ Class III, salfemane.

$\frac{\text{F}}{\text{Q, L}}=\frac{58.17}{0}=\infty.$ Order 5, gallare.

$\frac{K_2O+Na_2O}{CaO'}=\frac{59}{97}=0.61.$ Rang 3, camptonase.

$\frac{K_2O}{Na_2O}=\frac{9}{50}=0.18.$ Subrang 4, camptonose.

Symbol, III. 5. 4-3. 4.

Norm of II	
Q	1.44
Or	5.56
Ab	20.44
An	26.13
Di	13.90
Hy	20.03
Mt	3.02
Il	6.84
Ap	1.00
Rest	1.19
	99.55

Ratios of II

$\frac{\text{Sal}}{\text{Fem}}=\frac{53.57}{44.79}=1.20.$ Class III, salfemane.

$\frac{\text{F}}{\text{Q}}=\frac{52.13}{1.44}=36.20.$ Order 5, gallare.

$\frac{K_2O+Na_2O}{CaO'}=\frac{49}{94}=0.52.$ Rang 4, auvergnase.

$\frac{K_2O}{Na_2O}=\frac{10}{39}=0.26.$ Subrang 4-5, auvergnose.

Symbol, III. 5. 4. 4-5.

It is evident that both fall well within the salfemane class and the perfelic order gallare, though a very small amount of quartz is present in the norm of II. As regards the rang, which is based on the relations of the alkalies to salic lime, I falls in the alkalicalcic division, camptonase, but so close to the border of the docalcic order auvergnase that it must be considered transitional. II falls within the docalcic order auvergnase, but it may be noted that this position is due to the abstraction of the soda to satisfy the chlorine, present as sodium chloride derived from sea-water, and that, were this not determined, the rock would fall also in the alkalicalcic order camptonase, where it was placed when this analysis was published previously. This rock must therefore also be regarded as transitional. The subrang is, in every case, distinctly sodic, so that I is to be called auvergnose-camptonose, and II camptonose-auvergnose. Collectively, therefore, these rocks may be considered to belong to the transitional division camptonose-auvergnose, as they apparently tend to be docalcic.

Relations of norm and mode.—In these rocks the relations of norm and mode are quite simple and the readjustments needed to compute the latter from the former are confined almost wholly to those necessary to form the modal augite. As this mineral has not yet been analyzed, it is needless to go into any great detail, but it may be pointed out that these readjustments would, on the analogy of many other similar cases which have been worked out, consist in the transfer of a little of the normative anorthite, magnetite, and ilmenite, combined with the whole of the normative diopside, to the more complex modal augite molecule. The normative orthoclase, but little of which is present, must be considered as entering the modal plagioclase, though a small part of it may be present in the base of the ground-mass. As the augite is not markedly titaniferous, and the olivine presumably not more so, and as no titanium minerals, as perofskite, titanite, or ilmenite, are present, the very considerable amount of normative ilmenite (except that which enters the augite) must be held in the opaque ore grains, which, therefore, are to be considered as titaniferous magnetite.

But all of these readjustments are of comparatively small magnitude, even those needed for the formation of augite, which are moreover the normal ones, or those necessary in the case of the vast majority of igneous rocks, in which the pyroxene is aluminous. The modes are, therefore, normative and, in view of the abundance of feldspar phenocrysts, the Monte Ponente type may be briefly described as salphyro-camptonose-auvergnose, which indicates very concisely a basalt of about the chemical composition shown by the analyses, showing the mode in general described above, and with prominent feldspar phenocrysts.

The presence of a slight amount of quartz in the norm of II may seem to be inconsistent with the presence of olivine in the mode. But this is by no means uncommon, and instances of basalts containing olivine in the mode, while the norm shows none and even some quartz, are met with quite frequently, as along the Pacific slope of the United

States,[1] and in the fiescolal ciminose (ciminite) near Viterbo, which has been discussed elsewhere.[2] In such cases the analysis leaves no doubt that there is an excess of silica which, owing to the modal presence of olivine, must be increased in the mode over that shown by the norm, and is to be looked for either in the residual base of the groundmass or, as in the quartz-basalts, is present as clearly recognizable quartz.

Occurrence.—Basalts of this type are especially well represented at Monte Ponente, composing the extensive northern flows of this cone as well as the dike which cuts the tuff of Monte Pozzolana. Other representatives of the type are met with in many of the flows of Monte Vulcano, some of those of Monte Rosso and Monte Raneri, and in the basalts about the Scala Vecchia, which are probably derived from Monte Vulcano.

Gypsum in vesicles.—In parts of one of the lower flows of Monte Ponente, as noted above, the vesicles of the lava contain a white, crystalline substance, which was supposed to be a zeolite, in the field. Examination in the laboratory, however, shows that it is gypsum, and as such an occurrence is unusual for this mineral it merits a brief description.

The mineral forms thin crusts, which are distinctly crystalline, though no definite crystal forms are to be seen. It is soft (H = about 2), and slight crushing develops poorly defined cleavage flakes. Under the microscope these show rather low refraction and double refraction, which were not determined quantitatively. Two other cleavages are prominent (one better developed than the other), crossing at about 114°, that of the two minor cleavages of gypsum. The acute bisectrix lies in the acute angle of the cleavage rhomb, making angles with the cleavage trace parallel to $10\bar{1}$ varying from 12° 30′ to 14°, the corresponding angle for gypsum being 13° 39′. An analysis (on 0.2122^{gm}) gave the following results, the calculated values for gypsum being given for comparison:

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[1] See, for instance, *Professional Paper*, U. S. Geological Survey, No. 14, 1903, p. 289, hessose, Nos. 18, 23, 29, and p. 333, auvergnose, No. 32. Many other cases could be cited from this collection.

[2] H. S. Washington, *The Roman Comagmatic Region*, Carnegie Publication No. 57, 1906, p. 64

	Found	Calculated
CaO	32.04	32.56
SO_3	46.61	46.51
H_2O	20.70	20.93
SiO_2	0.48	.....
Fe_2O_3	trace	.....
	99.83	100.00

The occurrence of gypsum in vesicles of basalts is not mentioned in the standard works of Zirkel, Rosenbusch, Roth, Iddings, and Levy and Lacroix, but its presence has been recorded in the vesicular lavas and the fumarole products of Vesuvius[1] and Etna,[2] and it is also mentioned as present in the boiling water of the crater lake of Graham's Island;[3] though, on the other hand, no mention is made of its presence at some other volcanoes, as Santorini and those of the Hawaiian Islands. It may also be mentioned that I did not find it in the very similar lavas of the Catalan volcanoes, nor is it recorded by Fernandez-Navarro in his very complete description of these lavas.[4] It also seems to be absent from the basalts of Pantelleria, not being mentioned by Foerstner,[5] nor having been observed by me.

CAMPTONOSE (FELDSPAR-BASALT), IL FOSSO TYPE

Megascopic characters.—In general these lavas are rather lighter in color than those of the preceding type, being mostly light to rather dark gray, decidedly black lava being rare. They are also more apt to be compact, and highly vesicular forms are less often met with. While they are porphyritic, phenocrysts are less abundant, this being especially noticeable in those of feldspar, which are very few, somewhat tabular, but furnishing rounded outlines in the hand specimen, and are usually rather large, up to 10^{mm} long and 5^{mm} wide, though very small and inconspicuous ones are also present. The phenocrysts of olivine and of augite resemble those of the other type, both as to their characters and their amounts, and do not call for special mention.

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[1] J. Roth, *Der Vesuv*, Berlin, 1857, p. 369; and J. L. Lobley, *Mount Vesuvius*, London, 1889, p. 287.

[2] Sartorius von Waltershausen, *Der Aetna*, Leipzig, 1880, Vol. II, p. 525.

[3] H. Abich, *Vulkanische Erscheinungen*, Braunschweig, 1841, p. 75.

[4] Cf. "Formaciones volcanicas de la Provincia de Gerona," *Mem. Soc. Espan. Hist. Nat.*, Vol. IV, 1907, pp. 437–43.

[5] E. Foerstner, *Boll. Com. Geol. Ital.*, 1881, p. 533.

Microscopic characters.—The general features shown in the thin section are much like those previously described, though there are some well-marked differences in the most representative specimens of this type. The very rarely seen feldspar phenocrysts are of a labradorite, highly twinned, of about the composition Ab_1An_1, as in the previous case, and similarly no constant difference of any importance can be detected in the characters of the phenocrysts of augite and olivine, though those of the latter are more abundant than in the Monte Ponente type.

The ground-mass, on the other hand, offers more points of difference. Small tabular, highly euhedral crystals of labradorite are abundant, but they are usually shorter and stouter than in the other rocks, and the arrangement, instead of being diverse, is typically subparallel, giving rise to well-marked flow textures, which are especially clearly developed in the blocks from the tuffs. Olivine is rarely seen in the ground-mass, and the anhedra of augite and magnetite are closely like those described above. The abundance of dark, dusty grains is seen only in one or two cases, and these transitional toward the preceding type, but the interstitial, colorless base is here less apt to be isotropic and often shows a faint birefringence, indicating the presence of the nephelite shown in the norm. Its amount, however, is never very great.

Mode.—Owing to the impossibility of a satisfactory application of the Rosiwal method, the mode of the specimen analyzed was estimated by readjustment from the norm, and is approximately as in I below, that of the other type being repeated in II for comparison.

	I	II
Labradorite (Ab_1An_1).......	50	57
Nephelite..................	5	0
Augite.....................	20	26
Olivine....................	14	6
Magnetite (titaniferous)......	10	10
Apatite....................	1	1
	100	100

It will be seen that the relative amounts of salic and of alferric and femic minerals is about the same in the two, so that the ground-mass of the Fosso type must be more highly feldspathic than that of the Ponente type, much of the feldspar of which exists as phenocrysts, and this fact will account for the usually lighter color of the present rock. The amount of nephelite is small, and those of augite, magnetite, and apatite scarcely differ in both rocks, while olivine is distinctly higher in that from Il Fosso.

Chemical composition.—This was determined by the analysis of a specimen from a block in the tuffs of Il Fosso, the results of which are given below, along with the molecular ratios.

SiO_2	46.55	0.776
Al_2O_3	14.55	0.143
Fe_2O_3	3.17	0.020
FeO	7.88	0.110
MgO	8.61	0.215
CaO	8.75	0.156
Na_2O	3.71	0.060
K_2O	1.62	0.017
H_2O+	0.14	.....
H_2O-	0.03	.....
CO_2	none	.....
TiO_2	3.84	0.048
P_2O_5	0.55	0.004
MnO	0.10	0.001
NiO	0.12	0.001
	99.62	

Camptonose (feldspar-basalt). Block in tuff, Il Fosso, Linosa.

The general features of this analysis are closely like those of the two Monte Ponente rocks, even in the small details of titanium, manganese, and nickel. It may be noted, however, that this rock is very distinctly lower in silica and higher in alkalies, especially potash, while magnesia is a trifle higher and lime slightly lower, the other constituents remaining about the same.

Occurrence.—The most representative specimens of this type were met with as angular, compact blocks in the tuffs of Monte Levante, Il Fosso, and the north crater of Monte Bandiera, while other specimens, decidedly transitional toward the preceding type, occur as flows at Monte Vulcano and in the blocks of lava, apparently derived from Monte Ponente, which have been excavated at the Scala Nuova for use in building the jetty.

Classification.—The norm of this rock, calculated from the figures shown in the analysis, is as follows:

Norm	
Or	9.45
Ab	23.32
An	18.35
Ne	4.40
Di	17.05
Ol	13.53
Mt	4.64
Il	7.30
Ap	1.34
Rest	0.39
	99.77

Ratios

$\frac{\mathrm{Sal}}{\mathrm{Fem}}=\frac{55.52}{43.86}=1.27$. Class III, salfemane.

$\frac{\mathrm{F}}{\mathrm{L}}=\frac{51.12}{4.40}=11.62$. Order 5, gallare.

$\frac{K_2O+Na_2O}{CaO'}=\frac{77}{66}=1.17$. Rang 3, camptonase.

$\frac{K_2O}{Na_2O}=\frac{17}{60}=0.28$. Subrang 4, camptonose.

Symbol, III. 5. 3. 4.

This rock, therefore, falls well within the salfemane class, the amount of nephelite being negligible, and it is also clearly in the perfelic order, the alkalicalcic rang, and the dosodic subrang, and is thus an almost central camptonose.

The relations of the norm and mode, which are almost identical with those discussed above, need not be repeated here. The mode may be considered as normative, and the type may be briefly described as an alferfemphyro-camptonose.

CAMPTONOSE (OLIVINE-BASALT), MONTE RANERI TYPE

Megascopic characters.—This type differs from the preceding in the abundance and size of the olivine phenocrysts, which are olive-green in color, from 2 to 10^{mm} in diameter, and constitute at least 20 per cent. of the rock. Feldspar phenocrysts are tabular, as in the salphyric subtype just described, but their number is very few, and they are small and inconspicuous, as are also the phenocrysts of augite. Most of the specimens of this type which were collected are compact, but scoriaceous and vesicular forms also occur. On weathering, the compact forms show a feature which was also noted in some of the Catalan basalts, namely a peculiar mottled appearance in patches of dark and light gray, or dark gray and slightly reddish gray, the rock tending also to disintegrate into small, angular pieces which correspond to these colored areas. This appearance, which has been called *Sonnenbrand* by German quarrymen, is not uncommon in some basalts, especially in those which contain nephelite, and has been attributed by Leppla[1] to the presence of this mineral.

Microscopic characters.—In thin section the same minerals are seen to be present as in the preceding type but, corresponding to the megascopic characters, olivine phenocrysts are much more numerous. These are seldom euhedral, but usually present rounded outlines, which are frequently irregular, though embayments, such as are often ascribed to corrosion by the magma, are rare. The olivine phenocrysts carry some small inclusions of magnetite, and are occasionally slightly brown on the edges through incipient alteration. The few feldspar phenocrysts are of labradorite, about Ab_1An_1, thick tabular in shape, and frequently spongy in the interior through the presence of many inclusions of glass, augite, and magnetite. No augite phenocrysts were seen in the sections examined.

The ground-mass is somewhat coarser than in the preceding type, and the abundant, highly euhedral, labradorite tables are shorter and stouter, and an intersertal arrangement is not so pronounced. Small anhedra of colorless or yellowish augite and of magnetite are abundant, while small anhedra of colorless olivine are present in the ground-mass to a greater extent than in the preceding type, though they must be considered as but accessory ground-mass constituents. A glass base seems to be present occasionally, but its amount is very small.

Mode.—While no satisfactory estimate of the mode by Rosiwal's method was possible, the relative amounts of the various minerals present was readily estimated by some simple readjustments of the figures shown by the norm, which are given on a later page. The mode is approximately as follows:

Labradorite (Ab_1An_1)	47
Augite	11
Olivine	28
Magnetite (titaniferous)	10
Apatite	1
Glass and nephelite	3
	100

As compared with the modes of the preceding types it is clear that the most marked difference lies in the amounts of augite and

[1] A. Leppla, *Zeitschrift der praktischen Geologie*, Vol IX, 1901, p. 175.

olivine, the proportions of these being reversed. In the Monte Raneri type, also, the amount of labradorite is somewhat less than in the preceding rocks, while the ores and apatite remain about the same.

Chemical composition.—The results of an analysis made of the freshest specimen from Monte Raneri are here given. As compared with those of the preceding types the silica is decidedly lower than the lavas of Monte Ponente, but only slightly lower than the block from Il Fosso. Alumina, the oxides of iron, the alkalies, titanium, phosphorus, and manganese are almost the same; but lime is considerably lower, and magnesia, on the other hand, very much higher, these last features being in accord with the great abundance of olivine in this type and its comparative paucity in augite. Nickel also seems to be present in somewhat greater amount, and this is to be expected on account of the high content in magnesia, though the small figures are not very significant. Only a mere trace of chromium is present, and none of this was detected in the other rocks analyzed.

SiO_2	45.75	0.763
Al_2O_3	13.98	0.137
Fe_2O_3	3.23	0.020
FeO	8.02	0.111
MgO	14.69	0.367
CaO	7.11	0.127
Na_2O	3.10	0.050
K_2O	1.10	0.012
H_2O+	0.16	.....
H_2O-	0.04	.....
CO_2	none	.....
TiO_2	2.90	.036
P_2O_5	0.36	0.003
Cr_2O_3	trace	.....
MnO	0.06	0.001
NiO	0.14	0.002
	100.64	

Camptonose (olivine-basalt). Monte Raneri, Linosa.

Occurrence.—Typical examples of this rock were found only at Monte Raneri, where they seem to be the prevailing type, but a very similar lava was met with as blocks at Monte Rosso, in which, however, the olivine phenocrysts, while prominent, are fewer and smaller than in the Monte Raneri rock.

Classification.—The norm and ratios of the specimen analyzed are as follows:

Norm	
Or	6.67
Ab	22.01
An	20.85
Ne	2.27
Di	9.26
Ol	28.17
Mt	4.64
Il	5.47
Ap	1.00
Rest	0.40
	100.74

Ratios

$\frac{\text{Sal}}{\text{Fem}}=\frac{51.80}{48.54}=1.07$. Class III, salfemane.

$\frac{\text{F}}{\text{L}}=\frac{49.53}{2.27}=21.81$. Order 5, gallare.

$\frac{K_2O+Na_2O}{CaO'}=\frac{62}{75}=0.83$. Rang 3, camptonase.

$\frac{K_2O}{Na_2O}=\frac{12}{50}=0.24$. Subrang 4, camptonose.

Symbol, III. 5. 3. 4.

From the figures given it appears that this type falls well within all the magmatic divisions, and that it is a typical camptonose. The classificatory influence of the very high magnesia, in which respect it differs most widely from the other rocks analyzed, would be expressed in the minor divisions of the system, especially in the section of grad, which is based on the relations of olivine to pyroxene. But in the present introductory stage of the new system it is not deemed advisable to carry the classification as far as these minor divisions for ordinary purposes, since the main features of a rock may be quite clearly expressed by the use of the major magmatic divisions alone (from class to subrang inclusive), together with a typal qualifier or adjectival prefixes, to indicate the mode and texture.

So far as the relations of norm and mode are concerned, the readjustments needed to derive the mode from the norm are of slight importance, being confined chiefly to the augite, the amount of which is small, as we have seen above. The mode may therefore be considered as normative, and the rock may be described as an olivine-phyro-camptonose, which designates very concisely its mode, texture, and chemical composition. In the prevailing systems of classification it is an olivine-feldspar-basalt, but the use of a special name would be needed if it were desired to indicate the size and abundance of olivine phenocrysts, in which respects it differs from many others.

THE TUFFS

While volcanic tuffs, as a rule, offer few features of interest, yet as those of Linosa are so abundant and play such a conspicuous rôle in the formation of the cones of the earlier period, they may be described briefly.

These tuffs vary in color from dark, rather greenish, gray to a light brownish yellow. In some cases only one of these is present, as yellow tuffs at Monte Pozzolana and Monte Biancarella, or dark gray at the main ridge of Monte Bandiera; while elsewhere both varieties are met with, as at the two craters east of Monte Bandiera and at Monte Levante. As will be seen later, the differences between the two are probably to be ascribed only to differences in the progress of alteration.

The dark-gray tuffs are very fine grained and friable, readily rubbing down to an impalpable powder, at least in great part. Aside from the large blocks of lava which are embedded in them, they contain very small fragments of black basalt, seldom larger than a pea and running down to very small angular grains. A bedded structure is generally clearly manifest, and is frequently emphasized by thin layers more rich in the small fragments of basalt. Unfortunately, no sections were made of these, but the powder, when viewed under the microscope, shows fragments of colorless augite as the only recognizable mineral, the greater part of the mass being a dust of almost opaque, but apparently isotropic, minute grains, probably of glass.

The yellow tuffs[1] show, likewise, small pieces of black basalt, often vesicular, which stand out against the light-yellow background more prominently than do those in the gray tuff. The yellow portion is rather less friable than the preceding, and is somewhat porous, the constituent grains being agglomerated into very small, rounded aggregates, a millimeter or less in diameter, between which there are numerous crevices and pores. The powder of this, under the microscope, also reveals small fragments of augite, the light-yellow dust in which they lie being semi-transparent and apparently isotropic.

The chemical composition of these tuffs is shown in the two analyses given below, both analyses being made of average material which includes the very small fragments of basalt which seem to be always present. They were made on air-dried material, the specimens having been kept in a drawer for over a year prior to the analysis. None of the minor constituents, except titanium dioxide, were determined, but both manganese and nickel were present, and apparently in amounts comparable to those shown by the preceding analyses.

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[1] These are the trachytic rocks of Calcara.

	I	II	I*a*	II*a*
SiO_2	47.43	39.00	50.16	46.66
Al_2O_3	17.20	15.58	18.19	18.64
Fe_2O_3	4.20	6.13	4.44	7.33
FeO	5.27	3.11	5.57	3.72
MgO	4.85	6.55	5.13	7.83
CaO	7.56	6.82	8.00	8.16
Na_2O	3.53	3.22	3.73	3.85
K_2O	1.51	0.59	1.60	0.71
H_2O+	2.42	6.03	....	....
H_2O-	3.12	8.18	....	....
CO_2	none	1.83	....	....
TiO_2	3.00	2.59	3.17	3.10
	100.09	99.63	99.99	100.00

I. Gray tuff. Monte Levante, Linosa.
II. Yellow tuff. Monte Pozzolana, Linosa.
I*a*. Analysis I calculated free from water.
II*a*. Analysis II calculated free from water and carbon dioxide.

These analyses present some features of interest. The silica of I is about the same as that of the lavas, while that of II is very much lower. Also the alumina of I is distinctly higher than in the lavas,[1] while that of II is about the same as in these. In view of the evidently very considerable weathering which these tuffs have undergone, the much lower ratio of ferrous to ferric oxide, as compared with the figures shown by the fresh lavas, is not surprising. Magnesia is very decidedly lower in I than in the majority of the lavas, while in II it is but slightly so, but the figures for lime as well as for the alkalies and titanium dioxide do not differ materially from those in the fresh rocks. The presence of considerable water only driven off at a high temperature, and of carbon dioxide in II, is readily understood, but the high figures for water which is driven off at 110°, and which cannot be due only to the moisture of the sample, indicates the presence of a zeolitic cement, the amount of which must be very large in the yellow tuffs, in which calcite also is present, and which serves to explain their more coherent character.

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[1] This high alumina, taken in connection with the low magnesia, might be thought to be due to the common analytical error of partial precipitation of the magnesia with the alumina, owing to the presence of insufficient ammonium chloride. But this was specially guarded against, and the absence of magnesia from the precipitate by ammonium hydroxide was definitely proven.

While the processes involved in weathering are highly complex and involve the abstraction of certain constituents, and to a less extent the addition of others, and in varying amounts for each,[1] so that the calculation of the figures shown by the analysis of weathered rocks to a water- and carbon-dioxide-free basis cannot usually express the original composition of the mass, yet the figures shown in the last two columns, which have been calculated on this basis, are not without interest. In spite of the higher alumina and ferric oxide, and lower ferrous oxide and magnesia, which they show, they indicate that the tuffs are derived from basalts which did not originally differ chemically very materially from the later lavas, especially those of the Monte Ponente type. The scarcely appreciable change in the figures for the alkalies, however, those for soda being even slightly higher in the tuffs than in the lavas, would indicate that the original magma of the tuffs was distinctly higher in these, especially in soda, and that nephelite would probably have been present in considerable amount had they formed compact lavas. The somewhat higher soda in the blocks of lava from the tuffs (page 23), over those of the later lava flows, leading to the presence of nephelite in the norm, and probably in the mode, of these rocks, also points the same way.

In general, however, regarding the tuffs as weathered representatives of original basaltic ones, the processes of alteration seem to have been normal, as explained by Roth[2] and Merrill,[3] the latter especially pointing out the usually more rapid loss in magnesia than in lime.

Although the figures shown in I*a* and II*a* above are open to the criticism that they do not adequately represent the original magmas, yet it is instructive to examine the norms which they yield, which are given here, the ratios being omitted.

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[1] Cf. G. P. Merrill, *Rocks, Rock-weathering, and Soils*, New York and London, 1897, pp. 173–94.

[2] J. Roth, *Allgemeine und chemische Geologie*, Vol. III, 1893, p. 251.

[3] G. P. Merrill, *op. cit.*, pp. 218–24, 239.

	I*b*	II*b*
Or	9.45	3.89
Ab	31.44	31.16
An	28.08	31.69
Ne	....	0.71
Di	9.17	6.91
Hy	8.16	....
Ol	1.18	11.48
Mt	6.50	2.78
Il	6.08	5.93
Hm	....	5.44
	100.00	99.99

I*b*. Norm of I*a*, gray tuff of Monte Levante.
II*b*. Norm of II*a*, yellow tuff of Monte Pozzolana.

From these figures the gray tuffs, or rather the original rock on the assumption that the recalculated analysis correctly represents it, falls in the subrang andose (II. 5. 3. 4), while the original rock of the yellow tuff would fall in beerbachose (II. 5. 3. 5), but so close to the border of the docalcic order that it is nearly in hessose (II. 5. 4. 4–5), so that it should be called a hessose-beerbachose (II. 5. 4–3. 4–5). The most salient feature about these magmatic positions is the fact that, differing from the fresh lavas, these tuffs are in the dosalane class, not the salfemane. This position is brought about, in part by the high alumina, which increases the amount of normative anorthite, in part by the greater amount of ferric oxide relative to ferrous, and by the lower magnesia, both of which decrease the amounts of femic minerals. But apart from these differences of class, the rocks of the tuffs would seem to have been closely concordant, as far as the order, rang, and subrang are concerned, with the later lavas, and they were probably originally also in the salfemane class.

GENERAL PETROLOGICAL RELATIONS

Character and succession of the lavas.—The figures shown by the analyses, and the facts in regard to the relative ages of the various volcanic cones, presented in the preceding pages, furnish us with the data for a brief discussion of the general characters of the Linosa lavas, and their order of succession. For convenient reference all of the analyses of the lavas are repeated here, those of the tuffs being omitted, as their original characters are so obscured by weathering as to render these analyses of little use. There are also given in the table some analyses of closely related rocks from Pantelleria, Sardinia, and Catalonia, which have already been published,[1] and which will be referred to in the subsequent discussion.

The lavas of Linosa would seem to be quite monotonous in chemical as well as mineral characters. Mineralogically they are of very simple composition, labradorite, augite, olivine, titaniferous magnetite, and apatite being the only minerals present in all cases, and usually in about this order of abundance, though in one rare type the amount of olivine surpasses that of the augite. Chemically, they are

	I	II	III	IV	V	VI	VII	VIII	IX
SiO_2....	48.06	48.84	46.55	45.75	46.22	44.83	52.40	52.67	47.66
Al_2O_3..	15.90	14.62	14.55	13.98	12.23	11.73	15.26	15.35	14.36
Fe_2O_3..	3.37	2.08	3.17	3.23	4.91	1.35	0.74	3.82	2.83
FeO....	7.97	9.00	7.88	8.02	7.71	11.79	8.33	5.42	8.44
MgO...	7.11	7.15	8.61	14.69	6.74	5.50	7.45	4.40	8.19
CaO....	9.37	9.33	8.75	7.11	9.86	9.63	7.33	5.91	9.36
Na_2O...	3.19	2.86	3.71	3.10	3.39	3.34	3.54	4.50	3.51
K_2O....	0.85	0.89	1.62	1.10	1.13	1.40	0.99	2.68	1.54
H_2O+ .	0.40	0.49	0.14	0.16	0.17	0.81	0.29	0.37	0.17
H_2O- .	0.06	0.07	0.03	0.04	0.05	0.10	0.06	0.14	0.20
CO_2....	none	none	none	none	none	none	none	none	none
TiO_2...	3.31	3.57	3.84	2.90	5.68	6.88	3.12	4.04	3.83
P_2O_5...	0.36	0.36	0.55	0.36	1.46	2.14	0.49	0.75	0.45
MnO...	0.06	0.04	0.10	0.06	....	....	0.08	....	....
NiO....	0.09	0.08	0.12	0.14	....	....	0.06	....	....
	100.24	99.89	99.62	100.64	99.55	99.50	100.14	100.05	100.54

I. Auvergnose-camptonose (III. 5. 4–3. 4) [feldspar-basalt]. Upper north flow, Monte Ponente, Linosa. Includes Cl 0.14, CuO none.

II. Auvergnose (III. 5. 4. 4, 5) [feldspar-basalt]. Lower north flow, Monte Ponente, Linosa. Includes SO_3 0.05, Cl 0.42, SrO 0.04, and ZrO_2, CuO, and BaO none.

III. Camptonose (III. 5. 3. 4.) [feldspar-basalt]. Block in tuff, Il Fosso, Linosa.

IV. Camptonose (III. 5. 3. 4) [olivine-basalt]. Monte Raneri, Linosa. Includes trace of Cr_2O_3.

V. Camptonose (III. 5. 3. 4) [feldspar-basalt]. Monte San Elmo, Pantelleria.

VI. Camptonose (III. 5. 3. 4) [feldspar-basalt]. Island of 1891, near Pantelleria.

VII. Camptonose (III. 5. 3. 4) [feldspar-basalt]. Near Cuglieri, Sardinia.

VIII. Akerose (II. 5. 2. 4) [feldspar-basalt]. Monte San Mateo, near Ploaghe, Sardinia.

IX. Camptonose (III. 5. 3. 4) [feldspar-basalt]. Castellfullit, near Olot, Catalonia, Spain.

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[1] H. S. Washington, *Quarterly Journal of the Geological Society*, Vol. LXIII, 1907, p. 75.

characterized by rather low silica and alumina, high iron oxides, with ferrous oxide largely predominating over ferric, rather high magnesia and lime, the former being very high in the olivine-rich type, rather high soda (for such femic rocks), and low potash, very high titanium dioxide, small amounts of phosphoric pentoxide and manganese, and finally the constant presence of nickel oxide in rather high amounts for this constituent. Zirconium, chromium, copper, barium, and strontium seem to be either uniformly absent or present only in traces.

As regards the succession, or order of eruption, of the lavas, their uniform and monotonous character in general gives little scope for distinctions. From the figures furnished by the analyses of the tuffs and the blocks of the cones of the earlier period, however, as compared with those of the later lavas, it would seem that the earlier rocks were slightly higher in soda, and in general somewhat lower in silica and possibly in lime, than the later ones. The iron oxides, potash, titanium, and phosphorus apparently change but little, while there are indications of a slight drop in magnesia, though the high figure for this constituent in the Monte Raneri lava (which, however, is earlier than those of Monte Ponente) is anomalous. But the figures show, in general, variations of too slight an extent to justify any definite conclusion that a decided change has taken place, and indicate, on the contrary, that the chemical character of the magma has remained practically the same from the earliest eruption on Linosa to the latest. It is possible that this is connected with a short period of volcanic activity on the island, or it is possibly indicative of this. In the absence of any geological or stratigraphical means of measuring the time elapsed since the first eruptions, the interval between those of the tuff and of the lava cones, and the time that has passed since the last volcano became extinguished, we are not in a position to decide.

Relations of the Linosa lavas to others.—In a paper[1] published some years ago a possible genetic connection was suggested between the lavas of Linosa, Pantelleria, and Sardinia, the suggestion being based on the few analyses of the rocks of Pantelleria and Sardinia which had been published at that time, none of Linosa being known, as well as on some more general tectonic grounds. In a more recent paper,[1] based on numerous analyses which had been made of material collected during the trip on which Linosa was visited, especially of the basalts, the same idea was again expressed, the rocks of Catalonia being also considered as related to those of the other localities, and the probable existence of a distinct comagmatic region (petrographic province) in the western Mediterranean being pointed out. While this conclusion is based partly on the character of the basalts, there is considerable other evidence in its favor in the characters of the more salic rocks, and in other facts, but a full discussion must await the publication of the whole series of analyses, many of which remain to be made. In the present place it must suffice to point out the similarities between the basalts along this zone.

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[1] H. S. Washington, *American Journal of Science*, Vol. VIII, 1899, p. 293.

Turning to the table of analyses on page 32, it will be seen that the chemical characters of the basalts of Pantelleria, Sardinia, and Catalonia (only a few of which have been given here) are remarkably similar to those of Linosa and of each other. Except in Sardinia, where it is somewhat higher, silica is about the same in all, and the figures for the other constituents present close analogies with each other. This is especially well seen in those for the oxides of iron, ferrous oxide largely predominating over ferric, and those for titanium dioxide, the figures for this constituent, which reach a maximum at Pantelleria, being the highest known to me for any such large series of rocks. Also these basalts are highly dosodic, and in this respect in marked contrast to the salfemic rocks of the Italian peninsula, in which potash is abundant and is greatly in excess over soda, giving rise to the highly leucitic rocks for which the Bolsena-Vesuvius line of volcanoes is so famous.

While the general resemblance, and hence the probable genetic connection, between the basalts of Linosa, Pantelleria, Sardinia, and Catalonia are thus clear, it is noteworthy that the general monotony of the lavas of Linosa is in marked contrast with the conditions that obtain on the neighboring island of Pantelleria, as well as on Sardinia. On these two islands the earlier eruptions were of highly salic rocks, phonolites, trachytes, and rhyolites in the older classifications, being followed by, and the era of vulcanicity closing with, the eruption of more femic rocks (basalts), which formed small cinder cones similar to those of Linosa. It might be argued from this that the last eruptions of Linosa belong to a very recent date, subsequent to those of the earlier salic lavas of Pantelleria, and possibly contemporaneous with those of the final basaltic cones of this island. And this view is strengthened by consideration of the very recent submarine eruptions of 1831 and 1891 in the neighborhood of Pantelleria, the lavas of which are highly femic, and resemble those of Linosa and the last eruptions of Pantelleria.

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[1] H. S. Washington, *Quarterly Journal of the Geological Society*, Vol. LXIII, 1907, p. 69.